# Experimental Study on Mechanical Prosperities of Self-Compacting Geopolymer Concrete using Vermiculite as Fine Aggregate Replacement

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*Abstract*— Self Compacting Geopolymer Concrete (SCGC) is an innovative construction material in concrete technology. As the name replies, it does not need any compaction efforts, to achieve full compaction and utilizes supplementary cementitious materials (SCM) in addition with alkaline solutions like Sodium hydroxide and sodium silicate and super plasticizer as a binder for matrix formation and strength. In the present study, flyash based SCGC replaced with various percentages of VERMICULITE. The concrete specimens were cured at room temperature the results showed that the addition of GGBS to flyash based SCGC, the workability characteristics are decreased and strength was increased with increase in binder content. Hence the results showed that the SCGC was suitable for room temperature curing with VERMICULITE as replacement to fine aggregate based GPC.

***Key words:*** Geopolymer Concrete, Self-Compacting Concrete, SCM, Alkaline Activator, Room Temperature Curing, Vermiculite

## I. INTRODUCTION

Concrete is a vital ingredient in infrastructure development and with its versatile application, globally its usage is second to water. For several years, the use of cement as a binder in a concrete mixture has been often criticized by many parties concerned with environmental conservation. This is associated with global warming and depletion of significant amounts of natural resources in Portland cement production that became the main attention during the last decades. Global warming can be caused by greenhouse gas emission such as carbon dioxide, which occurs due to human activities in PC manufacture. So, to overcome this problem, the concrete use should be ecofriendly (or) environmental friendly. Geopolymer Concrete (GPC) is a new binder material that does not need the presence of Portland cement as a binder. Hence, instead of portland cement, we are using source of some source of Supplementary Cementitious Materials such as [Fly Ash, Ground Granulated Blast Furnace Slag (GGBFS), Rice Husk Ash (RHA), Silica Fume (SF), Metakaolin, etc., and these materials are rich in Silicon (Si) and aluminum (Al) are activated by Sodium Hydroxide (NaOH) and Sodium Silicate (Na2SiO3) alkaline liquids to produce the Geopolymer binder. Self-Compacting Geopolymer Concrete (SCGC) is relatively a new concept and can be regarded as the most revolutionary development in the field of concrete technology. SCGC is an innovative type of concrete that does not require vibration for placing it and can be produced by complete elimination of Ordinary portland Cement (OPC).

## II. GPC MIX DESIGN

Rangan and Hardjito (2005) have noted that unlike conventional cement concretes GPCs are a new class of construction materials and therefore no standard mix design approaches are yet available for GPCs. While GPC involves more constituents in its binder (viz., FA, GGBS, sodium silicate, sodium hydroxide and water), whose interactions and final structure and chemical composition are under intense research whereas the chemistry of Portland cement and its structure and chemical composition (before and after hydration) are well established due to extensive research carried out over more than century. While the strength of cement concrete is known to be well related to its water-cement ratio, such a simplistic formulation may not hold good for GPCs. Therefore, the formulation of the GPC has to be done by trial and error basis. The role and the influence of aggregates are considered to be the same as in the case of Portland cement concrete. The mass of combined aggregates may be taken to be between 75% and 80% of the mass of geopolymer concrete. The performance criteria of a geopolymer concrete mixture depend on the application. For simplicity, the compressive strength of hardened concrete and the workability of fresh concrete are selected as the performance criteria. In order to meet these performance criteria, the alkaline liquid-to-fly ash ratio by mass, water-to-geopolymer solids ratio by mass, the wet-mixing time, the heat-curing temperature, and the heat-curing time are selected as parameters. With regard to alkaline liquid-to-fly ash ratio by mass, values in the range of 0.30 and 0.45 are recommended. Sodium silicate solution is cheaper than sodium hydroxide solids. Commercially available sodium silicate solution A53 with $SiO_2$-to-$Na_2O$ ratio by mass of approximately 2, i.e., $Na_2O$ = 14.7%, $SiO_2$ = 29.4%, and water = 55.9% by mass, and sodium hydroxide solids (NaOH) with 97-98% purity are recommended. Laboratory experience suggests that the ratio of sodium silicate solution-to-sodium hydroxide solution by mass may be taken approximately as 2.5 (Hardjito and Rangan, 2005).

Mixture proportion of heat-cured low-calcium fly ash-based geopolymer concrete with design compressive strength of 45 MPa is needed for precast concrete products as follows:Assume that normal-density aggregates in SSD condition are to be used and the unit-weight of concrete is 2400 kg/m$^3$. Take the mass of combined aggregates as 77% of the mass of concrete, i.e. 0.77x2400 = 1848 kg/m$^3$. The combined aggregates may be selected to match the standard grading curves used in the design of Portland cement concrete mixtures. For instance, the aggregates may comprise 277 kg/m$^3$ (15%) of 20 mm aggregates, 370 kg/m$^3$ (20%) of 14 mm aggregates, 647 kg/m$^3$ (35%) of 7 mm aggregates, and 554 kg/m$^3$ (30%) of fine sand to meet the requirements of standard grading curves. The fineness modulus of the combined aggregates is approximately 5.0.The mass of low-calcium fly ash and the alkaline liquid = 2400 – 1848 = 552 kg/m$^3$. Take the alkaline liquid-to-fly ash ratio by mass as 0.35; the mass of fly ash = 552/ (1+0.35) = 408 kg/m$^3$ and the mass of alkaline liquid = 552 – 408 = 144 kg/m$^3$. Take the ratio of sodium silicate solution-to-sodium hydroxide solution by mass as 2.5; the mass of sodium hydroxide solution = 144/ (1+2.5) = 41 kg/m$^3$; the mass of sodium silicate solution = 144 – 41 =103 kg/m$^3$.Therefore, the trial mixture proportion is as follow: combined aggregates = 1848 kg/m$^3$, low-calcium fly ash = 408 kg/m$^3$, sodium silicate solution = 103 kg /m$^3$, and sodium hydroxide solution = 41 kg/m$^3$.

The sodium hydroxide solids (NaOH) with 97-98% purity is purchased from commercial sources, and mixed with water to make a solution with a concentration of 8 Molar. This solution comprises 26.2% of NaOH solids and 73.8% water, by mass. For the trial mixture, water-to-geopolymer solids ratio by mass is calculated as follows: In sodium silicate solution, water = 0.559x103 = 58 kg, and solids = 103 – 58 = 45 kg. In sodium hydroxide solution, solids = 0.262x41 = 11 kg, and water = 41 – 11 = 30 kg. Therefore, total mass of water =58+30 = 88 kg, and the mass of geopolymer solids = 408 (i.e. mass of fly ash) +45+11 = 464 kg. Hence, the water-to-geopolymer solids ratio by mass = 88/464 = 0.19. For water-to-geopolymer solids ratio by mass of 0.19, the design compressive strength is approximately 45 MPa, as needed. The geopolymer concrete mixture proportion is therefore as follows: 20 mm aggregates = 277 kg/m$^3$, 14 mm aggregates = 370 kg/m$^3$, 7 mm aggregates = 647 kg/m$^3$, fine sand = 554 kg/m3, low-calcium fly ash (ASTM Class F) = 408 kg/m$^3$, sodium silicate solution (Na2O = 14.7%, SiO2 = 29.4%, and water = 55.9% by mass) = 103 kg/m$^3$, and sodium hydroxide solution (8 Molar) = 41 kg/m$^3$ ( Note that the 8 Molar sodium hydroxide solution is made by mixing 11 kg of sodium hydroxide solids with 97-98% purity in 30 kg of water).

Geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. It is recommended that the alkaline liquid is prepared by mixing both the solutions together at least 24 hours prior to use. In the laboratory, the fly ash and the aggregates were first mixed together dry in 80-litre capacity pan mixer for about three minutes. The aggregates were prepared in saturated-surface-dry (SSD) condition. The alkaline liquid was mixed with the superplasticiser (SP) and the extra water, if any. The liquid component of the mixture was then added to the dry materials and the mixing continued usually for another four minutes. The fresh concrete could be handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength. The fresh concrete was cast and compacted by the usual methods used in the case of Portland cement concrete (Hardjito and Rangan, 2005). Fresh fly ash-based geopolymer concrete was usually cohesive. The workability of the fresh concrete was measured by means of the conventional slump test.

## III. MATERIALS

### A. *Flyash*

Flyash produced from sri damodaram sanjeevaiah thermal power station,Nellore,Andrapradesh was used. Flyash with specificgravity of2.20 was used. The chemical compositions are given in table 1.

### B. *GGBS*

Ground granulated blast furnace slag (GGBS) consists essential silicates and alumino silicates of calcium. GGBS obtained from Lanco steelplant, Srikalahastri, Andrapradesh. The specific gravity of 2.90 was used. The chemical compositions are given in table 1.

### C. *AGGREGATES*

Well graded locally available fine aggregates passing of 4.75 mm and coarse aggregate of passing 12.5 mm are used in the present work.

### D. *Vermiculite*

Vermiculite is a hydrous mineral group and is micaceous environment. Vermiculite is selected replace of fine aggregate in concrete because of its exact properties such as its lighter weight, superior, workability, superiorfire resistance.

### E. *ALKALINE ACTIVATOR SOLUTION*

The alkaline activator solution (AAS) plays an important role in Geopolymer concrete. The AAS is the combination of sodium hydroxide and sodium silicate solutions. The concentration of NaOH solution can vary in the range between 8M to 12M; In this study, 8M is considered. The NaOH for 8M is 8x40 (Molecular weight) = 320gms should dissolve in 1 litre of water. After mixing the NaOH flakes in water its molecular weight reduces to 320gms for 8 Molarity. For 8M NaOH solution, for 1 litre of water we require 32% of NaOH flakes and 68% of water. The solution must be prepared at least 24 hours before to use.

Table -1: Chemical Compositions

| Oxide | Flyash (%) | GGBS (%) |
|---|---|---|
| CaO | 3.20 | 37.34 |
| Al2O3 | 30.60 | 14.42 |
| Fe2O3 | 1.50 | 1.11 |
| SiO3 | 61.12 | 37.73 |
| MgO | 0.75 | 8.71 |
| Na2O | 1.35 | ---- |
| LOI | 0.79 | 1.41 |
| MnO | ---- | 0.02 |

### F. *SUPERPLASTICIZER*

Super plasticizer (SP) is an essential ingredient of SCC to provide adequate workability. In the present study, the SP used is supplied by ASTRAA Chemicals, Chennai in INDIA. Super plasticizer is used where a high degree of workability .It facilitates production of high quality concrete. It is appeared in brown colored liquid instantly dispersible in water. The optimum dosage is determined by trails with the concrete mix which enables the effects of workability and strength measured.

| Parameters | Proportions |
|---|---|
| Coarse aggregate (kg/m$^3$) | 935 |
| Fine Aggregate (kg/ m$^3$) | 829 |
| Binder (kg/ m$^3$) | 424 |
| NaOH Solution (kg/ m$^3$) | 106 |
| $Na_2SiO_3$ Solution (kg/ m$^3$) | 106 |

| AAS/Binder | 0.5 |
|---|---|
| NaOH / $Na_2SiO_3$ | 1:1 |
| SP (%) | 1.7 |
| Extra water (%) | 12 |

Table 2: Mix proportions

## IV. RESULTS

### A. *Fresh Properties*

The essential fresh properties required by SCGC are flowability or filling ability, passing ability and resistance to segregation. The tests performed on SCGC are Slump flow, T-50cms flow, V-Funnel, L-Box satisfying the EFNARC guidelines. The values are tabulated in table 3

Table 3: Fresh properties of SCGC

| Vermiculite % | Slump flow in Mm | T-50cms in sec | V-Funnel in sec | L-Box |
|---|---|---|---|---|
| 0 | 702 | 3 | 8 | 1 |
| 10 | 692.5 | 4 | 10 | 0.96 |
| 20 | 617.5 | 4.8 | 11 | 0.87 |
| 30 | 595 | 5 | 12 | 0.8 |
| 40 | 475 | 6 | 14 | 1.32 |
| 50 | 450 | 8.34 | 15 | 1.5 |

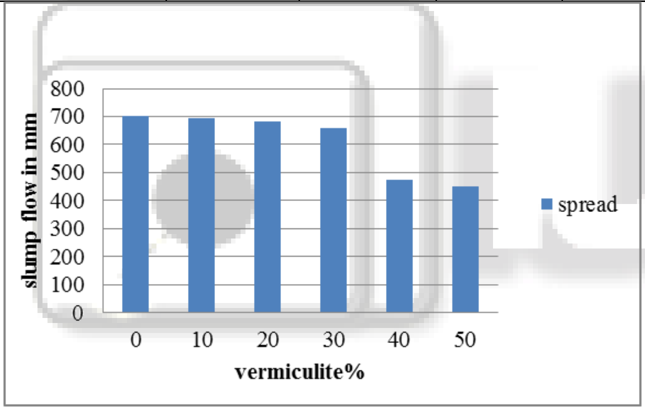

Fig. 1: slump flow

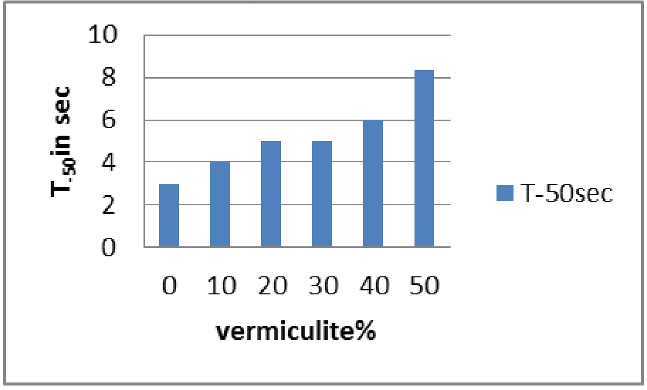

Fig. 2: slump flow

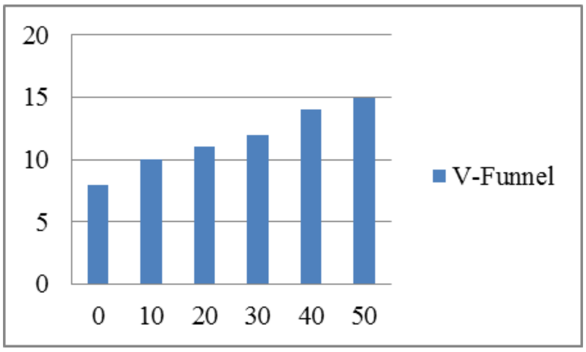

Fig. 3: V-funnel

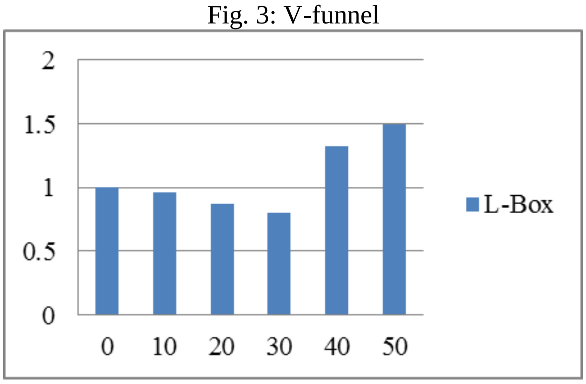

Fig. 4: L-Box

### B. *Hardened Properties*

The hardened properties are assessed by compressive strength, split tensile strength, ultrasonic pulse velocity and rebound hammer test. Compressive strength are calculated 7 and 28 days. Tests are done cubes at 10%, 20%, 30%, 40% and 50% replacement with fine aggregate. Spilt tensile test is done 28 and 56 days for 10%, 20% and 30% vermiculite replacement with fine aggregate

The values are tabulated in table 4 and shown in figures

| Vermiculite replacement with fine aggregate | Compressive strength Mpa | Spilt tensile strength Mpa | Ultrasonic pulse velocity(m/s) |
|---|---|---|---|
| 0 | 29.5 | 1.5 | 3826 |
| 10 | 26.48 | 1.38 | 3785 |
| 20 | 16.31 | 0.99 | 3695 |
| 30 | 12.5 | 0.81 | 3669 |
| 40 | 9.02 | 0.7 | 2953 |
| 50 | 5.02 | 0.6 | 2177 |

Table 4: Hardened properties of SCGC

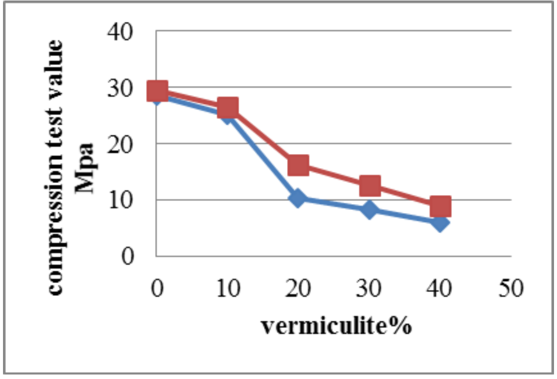

Fig. 5: compressive strength

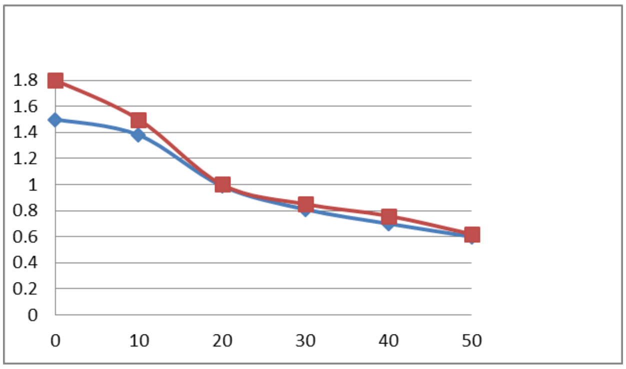

Fig. 6: spilt tensile strength

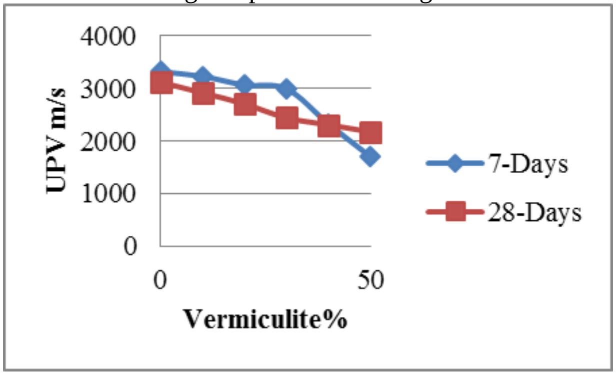

Fig. 7: ultrasonic pulse velocity

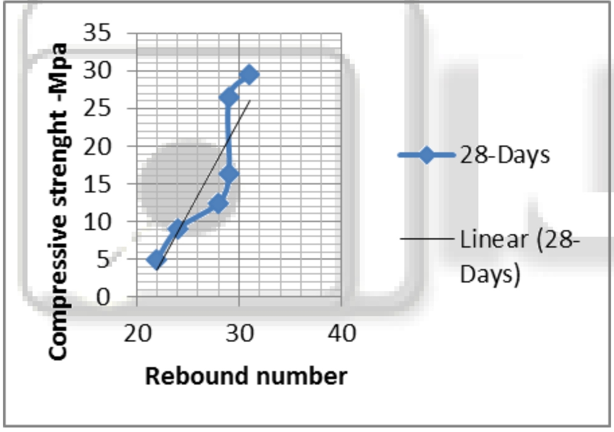

Fig. 8: Relationship between compressive strength and rebound number

## V. CONCLUSION

In this experimental study, the workability characteristics and strength properties of Fly ash and GGBS based SCGC assessed with different vermiculite replacements. From experimental results, the following conclusions are drawn:

- GPC offers environmental protection by means of recycling fly ash, GGBS, wastes or by products from industries, into a high volume of construction material for infrastructure development.
- The increase of VERMICULITE in the fly ash and GGBS based GPC reduces the workability characteristics.
- By adding VERMICULITE to fine aggregate replacement the strength was increasing and adding more VERMICULITE to fine aggregate strength decreases
- Economic benefits are achieved by reducing cost curing and labour for compaction.
- The SCGC is suitably designed for VERMICULITE replacement with fine aggregate up to 30% only and it is not suitable for 40% and 50%
- Lastly we concluded that 10%,20%and 30% of VERMICULITE to fine aggregate is suitable for self-compact geo polymer concrete (SCGC)
- It also can be used for thermal resistant structures

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